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FEASIBILITY STUDY OF AN ARCTIC FOOD PRODUCING FACILITY.(U)
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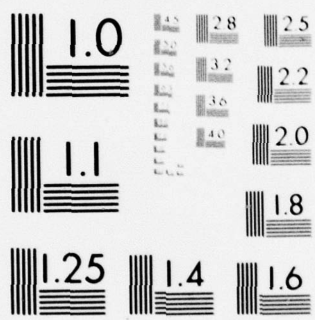

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ABSTRACT

This report demonstrates the feasibility of constructing an air-transportable hydroponic growth module for the year round production of lettuce, tomatoes, and cucumbers for up to 100 people located in remote northern communities. Preliminary comparative costs and technical considerations are presented for several different sized modules.

FEASIBILITY STUDY OF AN ARCTIC FOOD PRODUCING FACILITY

1. Introduction

Over the past decade, there have been renewed efforts by government, industry, and the military to develop and occupy the Canadian Arctic regions. Because of their remote geographical location, cold climate, and short growing season, food must be transported to inhabitants of many of the Arctic communities at great cost.

For example, Alert, in the North West Territories (82°N, 62°W); is a community largely cut off from the outside world. The Canadian Armed Forces must provide weekly flights of food year round by CC-130 aircraft (Hercules) from CF Base Trenton. (At the present time, Inuvik (68°N, 133°W) is the only other community in the N.W.T. that receives food weekly via the Canadian Forces on a continuous basis). In summer (May to September), 300 to 350 military and civilian personnel must be supplied with food; in the remaining months, about 200 people. A one-way flight to Alert (2700 miles from Trenton) with a fully loaded Hercules (usable payload 28,000 lbs) cost $1540 per hour, on average. This includes POL (petroleum, oil, lubricants), spares, repair, overhaul, in-service maintenance and depreciation. The flight crew (pilot, co-pilot, navigator, and two load masters) costs an additional $330 per hour. Thus, it costs the Canadian taxpayer about $0.57 for each pound of freight that makes the 8 1/2-hour flight to Alert. Of the payload, only 12,000 to 16,000 pounds consists of food. Thus, the transportation adds an average of $24 to $33 to the basic food budget for each person each week (1). This cost represents a major financial burden to the Canadian Forces, and any developments which can reduce or alleviate it must be given serious consideration.

2. Background

The Defence and Civil Institute of Environmental Medicine (DCIEM) is presently developing a combined water purification, waste disposal and sanitation system based on the Wetox principle in an air-transportable modular form for use in remote locations by 50 to 200 people (2). In addition to producing a sterile, disposable solid residue from sanitary and municipal-type wastes, the system also generates a liquid effluent waste which contains a relatively high concentraton of low molecular weight organics (e.g., acetic acid), phosphates, and ammonia salts. Moreover, there is a high concentration of CO_2 ($\approx$ 20%) in the spent air of the Wetox system as well as a low grade supply of heat ($\approx$ 200°F) in the effluent. DCIEM is currently conducting a feasibility study (3) on the use of this liquid effluent for the production of food by means of hydroponic gardening.

2.2 Objectives

In this report, we discuss the feasibility of growing food hydroponically in a growth module. Furthermore, a conceptual design of an air-transportable growth module is presented for the year round production of lettuce, tomatoes, and cucumbers in sufficient quantity to feed up to approximately 100 people in remote communities.

3. Food Production

3.1 Hydroponic Gardening

Hydroponics is the practice of growing plants without benefit of soil by feeding them on nutrient (chemical) solutions (4,5,6,7). There are basically two methods of growing plants without soil, both of which may be used in the open or in a "greenhouse". The first method, that of aggregate culture, relies on a sand or gravel-like material (e.g., Haydite) to support the root system of the plant. At periodic intervals, nutrient solution is forced from a holding tank into the aggregate bed at the base of the hydroponic unit (sub-irrigation technique) until it is partially flooded; then the liquid is allowed to drain back into the tank. The roots of the plants then become exposed to air until the next flood cycle begins. In this way, the two essential ingredients, nutrients and air, are continuously provided. The method of aggregate culture, using Haydite as the medium, has been successfully demonstrated at DCIEM in a greenhouse in which environmental factors were closely controlled. The second method, that of liquid culture differs in that the roots are constantly bathed in nutrient solution (see Section 3.3).

3.2 Advantages and Disadvantages of Hydroponic Gardening

Hydroponics offers several advantages over established horticultural practices. Briefly, some of these include: (a) the possibility for higher crop yield with uniform results (e.g. with tomatoes and cucumbers); (b) quicker growth since factors as pH, nitrogen, phosphorus, potassium, and others can be better controlled (particularly in a growth chamber); (d) the absence of weeds; (e) a reduction in growing area through closer spacing of plants; (f) a reduction in manual labour since the entire system can be automated, (g) the absence of waterlogging because of improper drainage; (h) out-of-season crop production (i) water and nutrient salvage and reuse thus reducing the natural wastages which are beyond control in standard horticultural practices; (j) transplantation of seedlings with relatively little shock; and (k) utilization of areas normally horticulturally unproductive.

There are three major disadvantages to hydroponic gardening. Improper attention to pH, temperature, essential element balance (macro and trace), and waterlogging runs the risk of poor plant growth, or, in the extreme, crop failure, a prospect which could make hydroponic gardening an expensive proposition. A second disadvantage concerns the substantial initial monetary outlay for capital equipment. Tanks,

pumps, growing troughs, piping and environmental control equipments can be quite expensive. The third major disadvantage is that not all vegetables can be successfully or economically grown in a hydroponic system, especially if they are grown "under glass". Varieties such as lettuce (leaf, endive), tomatoes, cucumbers, egg plants, pepper (hot, sweet), spinach, swiss chard, squash, strawberries, and onions are well suited for hydroponic cultivation. However, under normal conditions of supply and demand, it is unlikely that hydroponic vegetable production under glass is economically feasible. In remote areas, such as the Canadian Arctic, where transportation costs become prohibitive, hydroponically-grown vegetables are a definite commercial possibility as our calculations in this report indicate (vide infra). Harris (7) believes that, apart from tomatoes and cucumbers, hydroponically-grown produce cannot compete with normal methods of vegetable production in the south.

3.3 Nutrient Film Technique (NFT)

The major advantage of the NFT method of hydroponic gardening over aggregate culture techniques lies in the complete elimination of the substrate required for plant rooting (8,9,10). A second advantage is that the capital and installation costs are lower than in the aggregate system. A third advantage over aggregage cultivation is that only a small tank and one pump are needed to cover large numbers of plants.

The growing environment consists of continuous lengths of non-translucent plastic canals into which vegetables are spaced at regular intervals. Although the plant roots may be retained in cubes of rock-wood, woodfiber, or polyurethane foam, in the more sophisticated systems now being developed (10), the roots are suspended freely in the plastic gulleys. They quickly form a mat or rope which lines the entire gulley and the plant becomes as firmly "rooted" as in soil. The roots are constantly bathed in a circulating film of dilute nutrients, thus, the prime requisites of water, air, and inorganic ions are met.

3.4 Recommended System

In this study, the NFT method has been adopted for use in the air-transportable growth module. It is proposed that a trailer be obtained and outfitted as a growth module for the continuous year round production of tomatoes, cucumbers and lettuce. The trailer, which will be fitted for NFT cropping and will include a small service area, is to be designed to feed from approximately 20 to approximately 100 people (depending on its size). It is also proposed to air-transport the trailer to an Arctic community for testing.

The "per capita" consumption rates of fresh tomatoes, cucumbers and lettuce for the years 1974 and 1975 are given in Table 1 (11).

Table 1. "Per Capita" Consumption of Fresh Produce in Pounds per Person per Year.

Produce \ Year	1974	1975
Tomatoes	10.55	11.29
Cucumbers	3.39	2.92
Lettuce	17.23	18.21

For these consumption figures, and assuming that each plant provides 25-30 pounds of tomatoes in a 7-8 month harvest (average mass of a single tomato is 3/4 pound), it is anticipated that about 30 to 35 tomato plants would be required for continuous year round production for 100 people.

At an average weight of 14 ounces, and at 25-30 cucumbers per plant for a 5-6 month harvest, 6 to 9 cucumber plants would be required in the growth module to feed the 100 people year round.

For lettuce, the crop rotation cycle is about 40 days, thus 9 crops can be grown per year. At an average weight of 1/4 to 1/2 pound per lettuce bunch, approximately 4500 leaf lettuce spaces would be required.

Estimates indicate that approximately 30 lineal feet of trailer would be required to provide sufficient space to accomodate this crop of tomatoes, cucumbers and lettuce for year round production for approximately 100 people.

4. Modularized Facility Concept

4.1 Requirements

A prime consideration is the need to set up and evaluate the module and its internal systems in a southern location close to laboratory and machine shop facilities in order to allow optimization of the complete package. Specifically, this would ensure that construction of the module and its plant growth systems would be done by the people most experienced in building such units. Furthermore, the required skills and analysis would be available and be carried out in the most efficacious manner when assessing and modifying the performance of the complete system.

The module should be made readily mobile, taking advantage of the least expensive means of transportation to the Arctic, i.e., by ship. It should also be capable of being flown to land-locked villages year round. Limited ground transportation would also be required.

Space must be provided for the plant growth beds themselves, various additional areas, e.g. aisles, heating, ventilation, and air conditioning units, work areas for plant care and equipment maintenance, controls for environmental conditioning, hydroponic tanks and associated equipment.

Lighting for the plants should be of the order of 4000 foot-candles (ft-cdl) at the growing surface, with 6 ft of available head room above the plants. The walls should be surfaced with some reflective material able to withstand high humidity, such as stainless steel or Alzac-type aluminum sheet.

4.2 Description of Proposed Facility

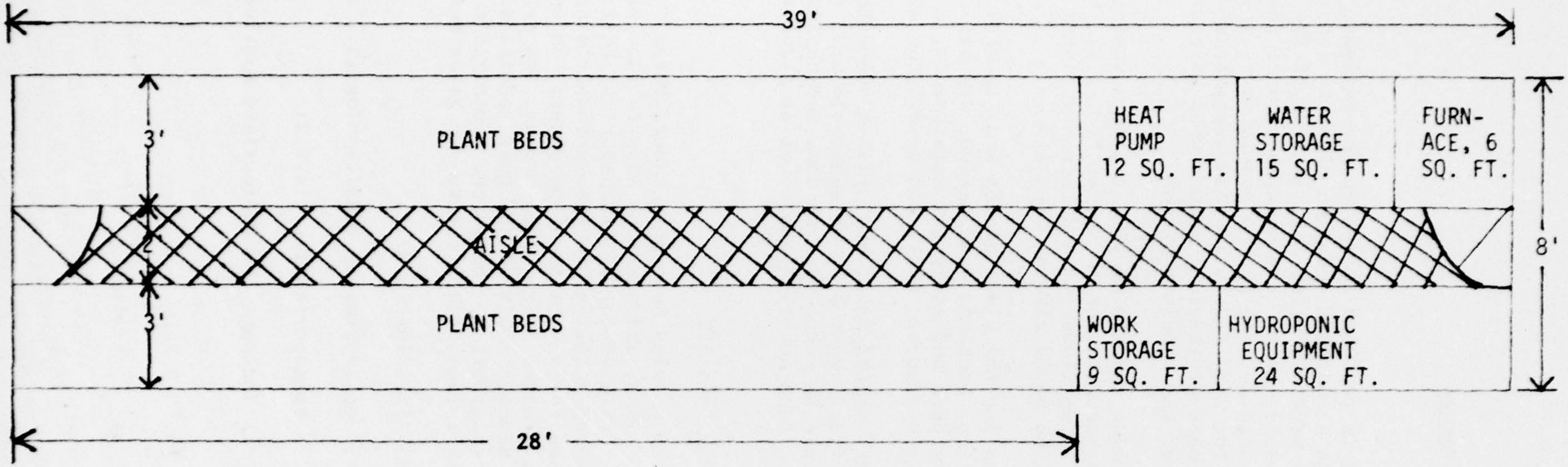
Transportable work-camp modules have been manufactured for use in oil and mining exploration camps, and numerous construction projects in remote areas. They can be designed for air transport by CC-130 aircraft and are generally custom outfitted to the purchaser's specification. As such, they have been used for a variety of purposes: as bunkhouses, dining areas, kitchens, recreation areas, pump-houses, and sewage treatment facilities. One of these modules could be designed specifically as an enclosed "greenhouse" for transport to the North. Specific design considerations necessary to meet these requirements are given below and include:

a) lighting (4.2.1),

b) environmental conditioning (4.2.2), and

c) transportability (4.2.3)

(where numbers in parentheses indicate the appropriate section in the text).



PLAN VIEW OF FULL SIZED "STANDARD" MODULE

OUTFITTED AS AN ARCTIC FOOD PRODUCING FACILITY

FIG. 1

In order to provide a reference point to allow comparisons and to judge the scale of the proposals outlined in this paper, data specifications given in the following discussion are based on the use of a "standard" maximum sized module approximately 39 ft x 8 ft x 8 ft. Figure 1 shows such a module with the areas required for the various functions of the greenhouse. While the height and width of the module should remain at 8 ft x 8 ft, any length may be considered. In Section 5, the cost factors for 3 module sizes are discussed.

4.2.1 Lighting

Light plays an essential part in plant growth since it provides energy for photosynthesis, the process by which plants manufacture carbohydrates from CO_2 and water. For normal plant growth, a proper balance of red and blue light is required. Standard incandescent lamps are rich in red light, but because they are relatively low in intensity they are usually only used for cyclic lighting in greenhouses. Blue light may be provided at high intensities by fluorescent lamps. Combined lighting (incandescent and fluorescent) is often used to provide the energy required for normal plant growth and shape. In completely enclosed growth chambers, high intensity discharge (HID) lamps are used for normal plant growth because of their greater efficacy, longer life, high lighting level, and good spectral balance.

There are two different HID lamps having sufficient intensity for proper plant growth in an enclosed growth module. These are: 1) sodium vapour, and 2) metal halide lamps. Both require electrical power of 400 watts per lamp, of which approximately 60 watts is dissipated at the ballasts. Each lamp irridates approximately 3.6 square ft of bed, and the lamps are arranged in pairs to provide overlapping beams, and are interconnected to allow at least two different illumination levels depending on the type of plant growth. In a 39-ft-long module, approximately 30 ft would be available for plant growth (see Figure 1). This would require 46 lamps. The total electrical load would be 18 kilowatts, all of which is dissipated as heat both at the ballasts (9000 BTU/hr) and throughout the interior of the module via the lamps (53,000 BTU/hr).

Desirable head room for plant growth is 6 ft, and this height can be achieved if the ballasts, which are about 2 ft in length and must remain vertical for cooling, are located remotely, such as on the walls of the module. This location is also preferable for module loading considerations, as the total weight of the ballasts is approximately 1000 pounds.

4.2.2 Environmental Conditioning

Two major operational modes must be considered for environmental control:

a) Winter operation. Heat loss through the walls and due to air exchange is expected to be only about 20,000 BTU/hr maximum during the coldest weather. Since the lamps and ballasts themselves provide 62,000 BTU/hr of heat, approximately 42,000 BTU/hr

will have to be removed during the 12 hours "on" cycle to avoid overheating the module. This is a considerable amount of heat and, if it were to be dissipated by ventilation with outside air, a prohibitively high operating cost would result. However, it would be very cost effective to store all of the excess heat for two purposes:

1) For use later each day as greenhouse-space heating when the lights are off and heat losses are still present.

2) For space heating in other buildings at any time.

This could be accomplished most effectively by means of a heat pump, a device which transfers heat from one medium (e.g., air) to another medium (e.g., water) at a higher temperature for storage purposes. Heat would be withdrawn from the air in the module when the lights are on, thereby cooling the interior. This heat would then be stored in a tank of water. Later in the day, when the lights are off and heat is required, the heat pump is operated in reverse, transferring heat from the water to the air. The quantity of water required to store enough heat for the full sized module with a typical 12 hour "lights off" cycle in the coldest weather would occupy approximately 100 cubic ft, or, 14 square ft of floor space. Besides saving the heat energy produced by the lamps, this system also has the further advantage (over *fresh air ventilation*) of minimizing vapour loss to the outside during the "lights on" cycle. Otherwise, during winter, humidifiers would be required to maintain the high humidity conditions necessary for optimal plant growth.

b) Summer operation. Under the warmest conditions during daylight hours when the lamps are on, 62,000 BTU/hr must be removed from the system. Taking into account the normal building solar heat load and an appropriate safety factor, a unit with a capacity of approximately 100,000 BTU/hr of sensible heat removal must be provided. Here the heat pump, acting as an air conditioner, becomes invaluable, since it allows storage of all the excess heat, for either remote or delayed use. With a conventional air conditioner, this heat would be irretrievably lost. It is assumed, here, that this excess heat can be utilized throughout the year. This is certainly true for far northern settlements such as Alert, and Arctic Bay which have in the order of 700 degree-days*/month of heating even in July, their warmest month.

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*One heating degree (^{o}F)-day results for each degree that the daily mean temperature is below the reference temperature of 65^{o}F.

4.2.3 Transportability

These modules are manufactured to order, and for local transport are typically fitted with either skids or wheels, or both. For long distance transport, the most economic form of transportation would be by sea, although the short shipping season in the Arctic might cause scheduling problems. However, as discussed earlier, the standard sizes most commonly employed can be carried within CC-130 aircraft.

It would be most advantageous to fully outfit the module in the south and to begin a crop before shipment. Normal handling and shipping procedures should not adversely affect any of the contents of the module, or the crop growth. Since the module is essentially self-contained, the only requirement is that adequate exterior ventilation be provided to allow for sufficient cooling within the module, and that there be an appropriate source of electricity.

5. Costs

Table 2 gives a breakdown of the cost for three sizes of modules: one, the maximum length capable of being transported by Hercules aircraft (39 ft), and two reduced lengths for comparison purposes (20 ft and 10 ft).

Total capital costs, capital cost per person, and the actual length available for plant growth are plotted against overall trailer length in figures 2 and 3.

The amortized cost is calculated on a 10 year term at an interest rate of 9%.

Electrical operating costs have been ignored since all of the electrical energy is ultimately converted to heat and this heat can be stored in a water reservoir and reclaimed later with a heat pump at any remote location to which the water can be pumped. Thus, all electrical energy supplied to the module, apart from that required for its heating, is completely recoverable for heating purposes elsewhere, and, hence could replace or supplement existing heating systems in northern communities.

6. Discussion

The total and per capita costs and usable growth length, as functions of overall module length, have been shown in Figures 2 and 3. If the module length is reduced to 10 ft from 39 ft, three significant points are apparent:

a) The capital costs per person increase almost two-fold;

b) The length available for plant growth decreases from 72% of module length to 50% (approximately a six-fold reduction in length for plant growth); and

c) The population served decreases by 81% while the amortized cost increases by 182%.

Excluding operation and maintenance costs, the lowest amortized cost would be \$0.85 per capita-week for the 39 ft growth module.

Using the typical consumption rates as shown in Table 1, the cost of flying the same quantity of food from the south to the Arctic as could be produced hydroponically is in the order of \$0.36 per capita per week.

Table 2. Breakdown of Costs for Fitting Three Sizes of Growth Modules for Hydroponic Food Production.

Item	Overall Module Length (ft)		
	39	20	10
Basic Module[1]	$10,300	$5,200	$2,600
Transportation[2]	$500	$500	$500
Heat Pump System	$2,600	$1,900	$1,600
Lamps	$7,700	$3,700	$1,500
Hydroponic Equipment	$2,000	$1,800	$1,500
Miscellaneous Controls, Wiring, etc.	$800	$800	$800
Total Capital Cost[3]	$26,290	$15,290	$9,350
Capital Cost/Capita	$283	$364	$519
Amortized Cost/Capita-Week	$0.85	$1.09	$1.55
Length of Module Available for Plant Growth[4]	28 ft (72%)	13 ft (64%)	5 ft (50%)
Population served	93	42	18

1 Includes independent heating, minimum lighting and basic wiring: approx. $33 per square ft.

2 $1.40/mile, from factory (Montreal) to DCIEM for outfitting

3 Includes 10% increase for escalation taxes, etc.

4 Percentage of overall module length in parentheses.

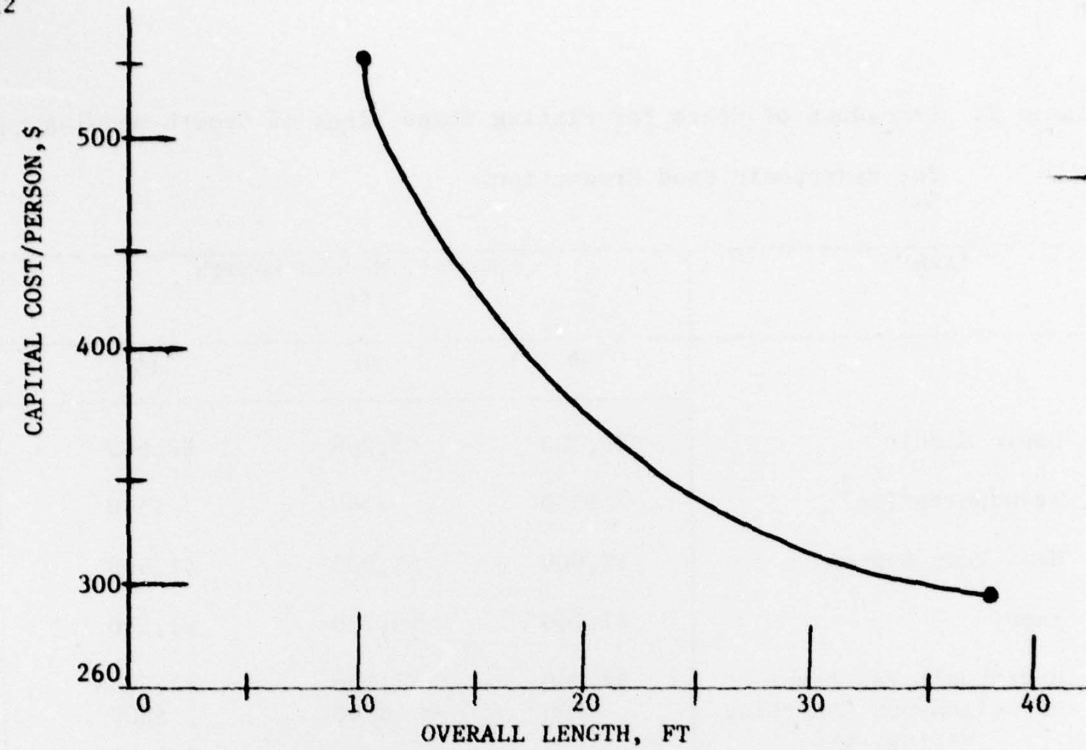

FIG. 2 Per Capita Module Costs

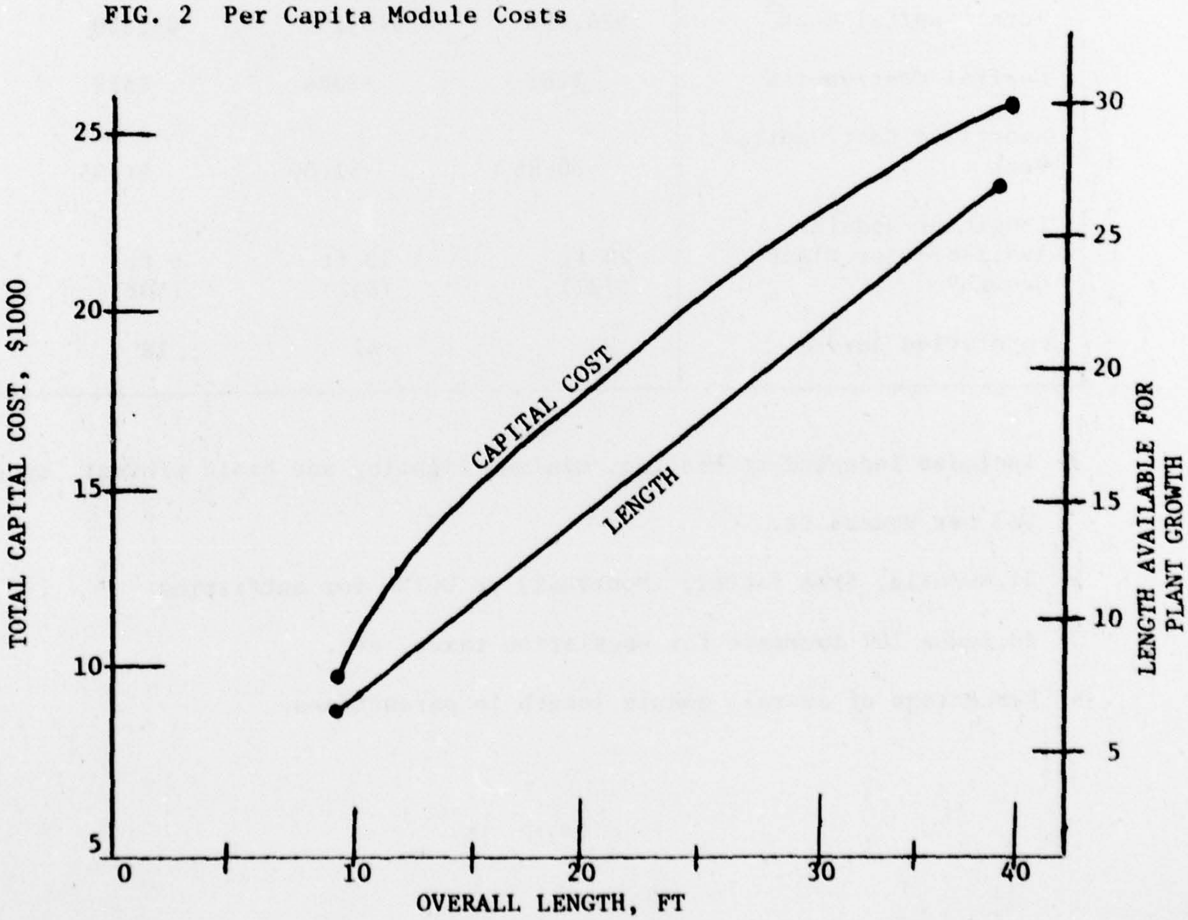

FIG. 3 Total Costs and Length Available for Plant Growth.

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